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Effects of water qualities of Kabul River on health, agriculture and aquatic life under changing climate

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ABSTRACT

The anthropogenic activities if not sensibly managed put enormous pressure on water resources of any country. Water quality of Kabul River has severely been polluted by rapid urbanization and industrialization. The sub lethal organic pollution is caused by discharge of effluents and other wastes into the river. The effluents from multiple leather processing units, and various other industries along with human feces and livestock manure are polluting the river ecology at an alarming rate. Climate is further impacting the quality of river and diminutive work has been done on climate change impacts on water quality. Integrated efforts are required to improve the water quality to reduce the morbidity and mortality rate in Pakistan and Afghanistan. In this review, water quality situation of Kabul River in Pakistan and Afghanistan along with potential impacts on health, agriculture and aquatic life under the changing climate scenario are presented. Water quality indices and modelling approaches for different parameters are suggested under the changing climate scenario which is expected to increase in the region to find the fate and transport of pollutants in the Kabul Rivers basin. Finally, recommendations were made to improve water quality of Kabul River and to decrease its adverse impacts.

Keywords: Anthropogenic activities; Climate change; Kabul River Basin; Modelling approaches; Physico-chemical parameters; Water quality index

1. Introduction

The earth's atmosphere has changed over the last two centuries due to anthropogenic activities that may take the earth's climate out of the stable range. Mean global temperature has risen by about 1°C as compared to 19th century, it is still projected to rise considering the trajectory of CO_2 emissions. International Panel on Climate Change (IPCC) in 2015 evaluated future climate changes and its impacts depending upon the emission scenarios of greenhouse gases and other manmade factors. In Paris Agreement, the different countries decided to keep the global mean temperature below 2°C while enduring the efforts to limit it to 1.5°C [1]. Thus, the rise of mean global temperature, sea level and precipitation lead to climate change that eventually deteriorates the quality of water. The changing air temperature and hydrological cycle are the main factors that affect the water quality in terms of

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climate change [2]. Water temperature is anticipated to rise because of global warming [3]. Physico-chemical parameters of water are governed by variations in water temperature, that changes concentration and transportation of contaminants in rivers [2,4]. It has also been examined that the concentration of dissolved oxygen (DO) is reduced in water by increase in water temperature. The duration and intensity of algal blooms are also affected by reduced DO concentrations [2,4]. The availability, variability of flow of rivers and seasonality are all affected by the climate change [4–7]. Multiple studies focused on the lower flow rates and higher water temperatures during summers that can deteriorate the water quality [6,7]. Due to increase nitrification rate, the ammonium concentrations also decrease with resultant increase in nitrate concentrations in summer season under reduced water flow.

Water quality is one of the serious issues throughout the world but more thoughtful in developing countries especially in Pakistan [6]. Water quality is deteriorating due to rapid urbanization, industrialization, high population density, lack of awareness and improper treatment at the source. Water scarcity, aging infrastructure, increased water demand and supply difference are gaining concerns in the country. Changing climatic conditions and poor management lead to water scarcity, and poor water quality. Pakistan ranks at number 80 among 122 nations regarding contaminated drinking water quality [8,9]. Due to several reasons, the mortality rate of children who are under-five is 101 deaths per 1,000 children in Pakistan. An estimate of 60% child mortality cases in Pakistan are caused by water and sanitation related diseases. The public health impact of water-borne diseases has series of challenges. Efforts to evaluate such burden include accounting of infections [5,9] mortality and incidence. Thus, a more logical and reliable approach is desired to enable comparison between the overall impact of diseases. An estimated 88% of diarrheal diseases are linked to unsafe water supplies [3] such as waterborne protozoa like *Giardia* and *Cryptosporidium* spp. also appears on surface water and in drinking water facilities [10–12]. The environmental factors also contribute an important role for the development of protozoa and other pathogens, in drinking water supplies. Through the faeces of infected animals, mainly cattle, *Cryptosporidium* oocysts are passed on. Oocysts live for more than a year and distribute on land [12], hereby transfer into the water bodies under the favorable conditions. Robertson et al. [13] and Graczyk et al. [14] studied that the pathogen contamination of water bodies, mainly surface waters, is caused by the sewage effluents. The close observations to the current scenario revealed that the water quality contribute a lot to human health. The annual social rate of return would be about $160 billion [14,15] if only 1% of the roughly 1.7 million yearly deaths from diarrheal diseases worldwide could be prevented by water disinfection.

Due to increase in average temperature by 0.6°C over the last 10 y, summer season is becoming warmer while shifting the seasonal pattern heavily impacting water availability and quality. Similarly, total water demand for all the sectors has increased between 7%–11% during the last two decades [16]. The climatic and soil conditions allow the pathogens to survive for longer periods once the pathogens are washed from river bodies. The present study is focusing on the water quality of river Kabul both in Pakistan and Afghanistan and its impacts on health, agriculture, and aquatic life with reference to climate change and studies related hydrometeorological modelling and water quality index has been presented. Missing research gaps have been identified for future work.

2. Methodology

2.1. Kabul River and catchment description

Hindu Kush Mountain Range in Pakistan is the source of origin for Kabul River. The river then travels westward and enters in eastern Afghanistan. It flows for about 480 km before joining River Indus at Attock City in Pakistan. During its journey in Afghanistan, it travels through Kabul (Capital), Logar and Nuristan Provinces of Afghanistan. In Afghanistan, the path of Kabul River (KR) supports three major basins, that is, Kabul, Paghman and Logar Basins of the supported by small streams and local rivers [17]. Kabul Basin near Kabul City has been supported by 04 aquifer systems consisting of combination of sand and gravel mostly deposited by river in the form of terraces. The Paghman basin has two dominant aquifer systems associated with the Paghman River and upper part of Kabul River. The Logar Basin is also equipped with two major aquifer systems, these systems mostly lie near the path of lower Kabul River. The groundwater recharges from seepage, infiltration, floods (in case of snow melts), irrigation ditches and industrial seepages. The Kabul River, Paghman and Logar Rivers describe the catchment of Kabul River Basin in Afghanistan. Afghanistan has usually arid continental climate with very hot summer and cold winter. The precipitation mostly takes place during the winter, the average precipitation in Kabul City is 500 mm/y and it increases in provinces of Kunar and Nuristan near Pakistani border (up to 1,000 mm/y) [18].

The Kunar River is shaped by the connection of Chitral River and a branch from Nuristan joins the Kabul River near Jalalabad (Fig. 1). The river finally reaches Warsak Dam after flowing through the Khyber and Mohmand Agencies bordered by the Kohi-Safed Mountains underneath Warsak Dam. Below Warsak Dam, the Kabul River again divides into three main branches, which are Adezai, Naguman and Shah Alam [19].

The three tributaries re-join after flowing for about 34 km. The river flows about 70 km in Pakistan. It has been observed that the depth to width ratio of river is highly variable at multiple places and in different seasons. According to an estimate, the approx. depth and width varies from 6–10 ft and 100–300 ft, respectively in Pakistan. The average monthly temperature is maximum in July, and mean monthly precipitation is maximum in April and August during the year while 80% of the annual flows occur during the months between April to September with a maximum in August [20]. The Kabul River (KR) is mostly used for irrigation, watering livestock, waste and effulent disposal, fishing, and bathing. The geology of river is quite complex as the lower basin is underlain by sedimentary limestone and shales that are shared in Indus Basin. The river channel, through the hills along the Pakistan–Afghanistan

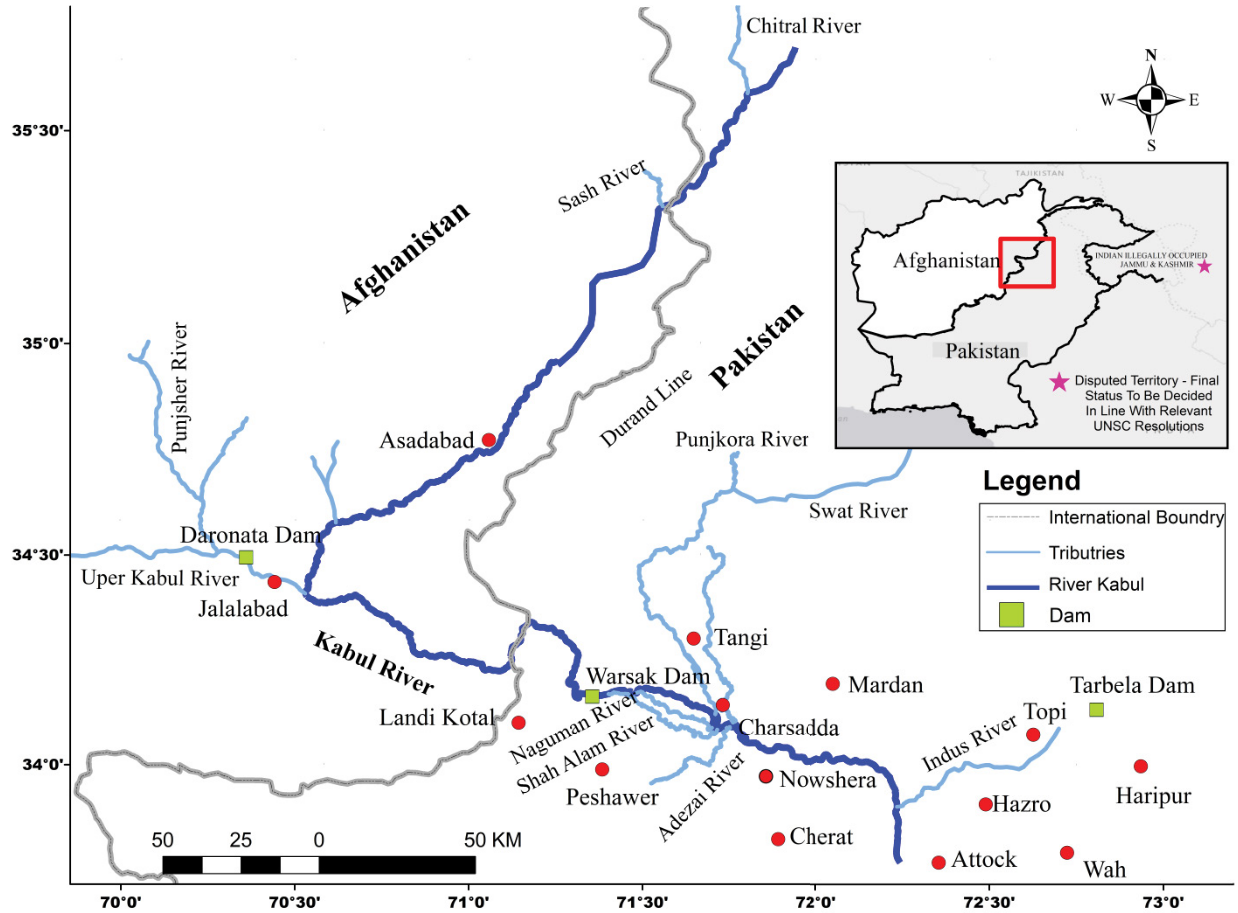

Fig. 1. Map of Kabul River showing network of tributries.

border confirms pre-exists of sedimentary rocks in the region through geomorphological evidence [21].

2.2. Data collection

Relevant literature was collected from the data bases like Google Scholar, Scopus, Science Direct and ISI Web of knowledge. Literature published on the authentic websites was covered by using simple search with Google and reports published during 1980–July 2020. The relevant publications and literature search was carried out by using the following key words: water quality of Kabul River, impacts of climate change on water quality, water quality index of KR, Modelling approaches of KR, water management of Kabul River, chemical water quality of Kabul River, biological quality of Kabul River, impacts of Kabul River water on human, agriculture, aquatic life etc. The most relevant articles and web-based information was carefully considered based on inclusion and exclusion criteria, and appropriate references were subsequently included in this review. According to the exclusion and inclusion criterion, most relevant studies matching key words and period were considered. The literature which was not relevant (covering other aspects) was ignored and not referenced as per exclusion criterion. Literature was critically analyzed, cited and experts view was given where needed and thereby giving recommendation for actions to improve the water quality status of KR and further suggested the need to assess the impacts of climate change on water quality, health, agriculture, and aquatic life along with modeling approaches for the pollutants under changing climate.

3. Results

3.1. Water quality scenario of Kabul River in Pakistan

It has been documented that tens of thousands of gallons of untreated waste water from Kakroyan Wastewater Treatment Plant has been dumped into the Kabul River as a result diseases such as gastrointestinal issues have been found in approximately 3,000 families that reside near the Kabul River in Afghanistan [22]. In addition to that in Logar Province several mines have been running that dump their contaminated water into the river thus deteriorating the river water quality. The water quality deterioration in Afghanistan is less due to scattered population and no major industrial zone in the vicinity of the river as compared to Pakistan. Quality of river Kabul is at its worst after entering into Pakistan because of multiple industrial units like sugar, oil, ghee, and pharmaceutical around its vicinity, Nowshera and Charsadda are the main districts where these industrial units and tanneries are present [23]. The river water is highly polluted with several toxic metals and effluents. The human lives are suffering because of bad water quality [24]. The livestock is also suffered by severe maladies due to polluted river water both in Afghanistan and Pakistan. Physical, chemical and biological water quality is affected by the pollution generated from industries and homes [25]. The pollutants have significant impact on water quality of Kabul River especially at Peshawar City. Empirical studies have reported the impacts of waste on water quality and subsequently on human health. Pollution level becomes high after passing water from upstream to downstream. Poor water quality at Peshawar and Nowshera has been reported by many studies [26–29] because Kabul River water is used as waste disposal sites. Aquatic life survives at upstream, and people of nearby areas are witness of aquatic life survival but at downstream, water quality is badly affected.

Water shortage and quality are big issues in many parts of the world, especially among the developing countries including Pakistan. It is predicted that more countries in the world will experience the water shortage soon and this leads to deterioration of water quality. As reported in recently published Assessment Report 5 of International Panel on Climate Change (IPCC) [30] that most of the developing countries will face water shortage due to increase in population density. Also, the impacts of climate variability on seasonal precipitation will exacerbate the situation leading to severe shortage of available clean water for masses [4,28]. According to WHO 2015 [2,31,32] population growth rate in Pakistan is 1.67% (2012) and increasing with time which has great influence on water resources. The drinking-water quality of river Kabul was found highly deteriorated with chemical and bacteriological pollutants making it unfit for human consumption. Lack of environmental protection measures such as inappropriate disposal of waste/wastewater and non-systematic application of agrochemicals have caused quality deterioration of river leading to various waterborne diseases to the people living nearby. However, the current data evaluated various management practices adopted for ensuring source and drinking water quality in river Kabul [18,33].

Many empirical studies conducted in Pakistan, have indicated both quantity and quality issues in many parts of the country. Many studies conducted in the South and Central Asian Region also pointed out the impact of anthropogenic activities on our water resources. Both surface and water quality are affected and shortage of surface water putting huge pressure on ground water. A study was conducted to find out spatiotemporal patterns in water quality of Soan River and analyzed the prep and post monsoon situation in 2008. The study showed the impact of anthropogenic activities on the river water and suggested the effective waste management measures [18]. Investment in water quality and sanitation is quite low (0.26% of Gross Domestic Product – GDP) and 0.18% is the direct share of government of Pakistan [14].

As the river Chitral, Swat, Bara are the major tributaries of river Kabul so relevant literature review has been collected on these tributaries as well. According to International Union for Conservation of Nature (IUCN) report [34] the DO was high and the biological oxygen demand (BOD) was low in Chitral River as one of the tributary of KR, whereas the dissolved and suspended solids were together high, almost definitely due to the catchment features. Level of sulphides was high, although the pH of the water is likely to render them less toxic. Examination of Swat River indicates that it is a relatively clean river. DO is high and BOD is low, whereas ammonia and its breakdown products are totally absent, as are sulphides. Organic pollution and fecal coliforms were also present in all samples, making the water bacteriologically dangerous for drinking. This is mostly due to sewage discharge from several large villages along the Swat River. Heavy metals were below detectable limits and over all there was no evidence of industrial pollution. Bara River is also a small tributaries of Kabul River in Pakistan side. The Bara River is also loaded with industrial effluents including ghee plants and marble works, as well as some village sewage with high suspended solids (more than 7,000 mg/L) [35]. The level of *E. coli* in the Kabul River was high and suspended solid varied 10–100 mg/L in low flow while 340–1,310 mg/L when there is high flow. KR water is a potential threat to human's population in the vicinity of the river. The Kabul River pollution is produced by discharge of local, domestic and industrial waste water directly into the river without any treatment, open defecation by people, runoff from agricultural land into river as animal manure is used in the fields as fertilizers [18]. Similarly, water parameters were analyzed and reported that pH, total dissolved solids (TDS), conductivity, total suspended solids, alkalinity, salinity and chlorides were increased (Fig. 2a and b) down the river and further reported that Swat River highly influence the water quality of KR as increase concentration of nitrites, nitrates, and ammonia were found after the input from Swat River tributary [36].

About 80 multiple industrial units release their crude effluents directly into the river. The raw discharge pollutants have deteriorated the river and sub-surface water of the area as well [37,38]. The major industrial units near Kabul River Basin are pharmaceutical, oil, ghee, textile, paper, sugar, soap, and tanneries. The industrial effluents in River Kabul have caused the noticeable decline in whole fish population in common. On the other hand, Mahaseer, Tor putitora (Hamilton) fish population have reduced in specific because of their extreme sensitivity to oxygen depletion due to the effluent pollution [35]. The river water is no longer fit for drinking purpose [39]. The pollution level during high Q-summer and low Q-winter discharges was assessed when water samples of Kabul River encompassing physico-chemical parameters upstream and downstream were compared with the water samples of Warsak Dam. The results showed that the organic pollutants load into the river is high which is confirmed by the larger values, that is, 290.5, 280 mgO_2/L for low Q and 295.7, 281.7 mgO_2/L for high Q periods of BOD in contrast with the National Environmental Quality Standards (NEQS) value of 80 mgO_2/L set for this variable. The downstream river water is reported with higher concentration of total suspended solids, BOD, NH_3, Cl^- and SO_4^{2-} than in the upstream water during low Q (winter) [15,19]. Another study revealed that the DO demand was good and above the recommended levels of 5 mg/L for aquatic life. BOD values were within the permissible limits while chemical oxygen demand (COD) was high under low flow conditions. The downstream river part is life threatening for fish population because of high total ammonia levels in water that might exceed 2 mg/L [40]. Nitrite concentrations in water bodies indicate presence of industrial effluents. High nitrite concentration was also examined in Bundi Nullah on Shah Alam [21,41]. The most probable reason of higher nitrite levels at one place is because of the presence of ammonia which converted into nitrites through the process of nitrification. Higher nitrate levels indicate high waste deposition by humans, and animals. The nitrates concentrations higher than 5 mg/L are indicating the deteriorated water quality but in some cases the concentrations may reach up to or more than 200 mg/L which indicates severe nitrate pollution in the river. The nitrate concentration was found to be within the permissible levels over Kabul River. Due to the acid waste discharge, the sulphide concentrations are higher in the river, that is, 0.74–1.82 mg/L [38].

The quality of Kabul River water at Amargarh, Nowshera was also analyzed in detail. Water samples from different industries were evaluated. The results showed local pollution within half km after the convergence point where the river quality is being damaged. The detailed analysis of effluents is mentioned in Fig. 3a and b [42,43]. The results showed high COD, nitrite–nitrogen, and low DO concentration in water samples. The concentration of cations and anions was also examined and found high in effluents samples (Fig. 3a and b). Moreover, no change was observed in pH and nitrate–nitrogen in samples. The study revealed that the overall pollution is high in summers as compared to winters. The high pollution level may be attributed to the seasonal variations as the flow of water in water bodies is more in summers than winters. It has also been estimated that the extent of pollution is declined considerably during summers because of high dilution factor. Due to this, all the values of multiple parameters shown in Fig. 3a and b according to different seasons (summers, autumn, winters, and spring).

Persistent organic pollutants like HCH and DDT in water resources are ecotoxicological risk in Pakistan. A study conducted on monitoring of persistent organic pollutants (POPs) in Kabul River sediments collected from different depths reported that presence of hexachlorocyclohexane in sediments of Kabul River is the main ecotoxicological concerns and use and spread of pesticides can cause serious health issues both in aquatic and human life [35]. Another study reported the water quality parameters like faecal coliform, pH etc. were within the permissible limit except DO and reported suitable for aquatic and agriculture use but not fit for drinking purposes as shown in Table 1 [44].

3.2. Surface water quality of Kabul River along Afghanistan

During 2006 to 2007, 77 water samples were collected from 8 rivers by United States Geological Survey (USGS) [45]. Different parameters were analyzed in sampling like specific conductance of surface water was estimated to be 67 to 1,497 μS/cm at Barik Ab River on the other hand, the median specific conductance on sub-basin ranged differently such as 111 μS/cm in Paghman River, also called Upper Kabul/Paghman subbasin. The concentration of calcium bicarbonate was found high in Kabul River. In Barik Ab, Logar and Kabul River at Tang-e Gharu, maximum variations were observed, that is, the samples contained more ions like sulphates and chlorides. It was observed that during spring-melt high flow time, the concentrations of chemical constituents were minimum on the above-mentioned sites while high chemical concentrations were estimated during low flow periods. The median specific conductance in Istalif and Paghman Rivers, flowing into Kabul Basin from upland regions, was low, that is, 140 and 111 μS/cm respectively. The concentrations of nitrates ranged from 0.4 to 5.9 mg/L in Paghman and Barik Ab River respectively while the median concentrations ranged from 1.0 to 2.9 mg/L in Paghman and Tang-e Gharu, respectively. Total coliform concentration at Paghman River ranged from 116 to at least 2,420 colonies per 100 mL in Kabul River at Tang-e Gharu and Barik Ab River. 7 surface water localities were analyzed and found contaminated with *E. coli* 2,420 per 100 mL *E. coli* colonies were monitored in Kabul River at Tang-e Gharu, Istalif and Barik Ab River. These high values of total coliform and *E. coli* is a big threat to deterioration of surface water and its impacts on the water users and need urgent attention.

3.3. Water quality and river pollution index of Kabul River

Water quality index (WQI) is a single number that describes the overall description of the quality of water. It identifies water quality by looking at a single aggregate obtained by utilizing large number of water quality parameters and expresses the water quality in a manner such as “very good”, “good”, “poor”, etc. [46–48] Water quality and river pollution index indicated medium to poor water quality as we move down the river while the river water had low salinity and alkalinity and rich in nutrients which is coming from agricultural and geological sources activities [35]. No other studies have been found on water quality index, however studies on other rivers like Chenab showed overall water quality indices showed poor drinking water and borderline for aquatic and agriculture activities [35]. For comparison, further studies are suggested on water quality index of Kabul River.

4. Discussion

4.1. Climate variability and its impacts on water quality of Kabul River

Climate variability and especially change in rainfall patterns have significant impacts on water quality. Flash flood may spread agricultural and other wastes into surface waterbodies. A study conducted in Afghanistan on Kabul River Basin using climate projections. Temperature and precipitation were projected for three future periods, that is, 2020, 2050 and 2080 against the base line period from 1961–1980. The mean annual temperature in the basin is projected to increase whereas the precipitation may increase or decrease depending upon months of year, by 2100 [49,50]. Another study analyzed the meteorological and agricultural drought between 2000 and 2018 and their future projections from 2020 to 2030 in the Kabul River Basin. The basin experienced meteorological and agricultural drought between 2000 and 2018 [51,52]. Study conducted at Nowshera about seasonal variation on bacteriological water quality of KR and physico-chemical properties reported more TDS, total coliform, and total bacterial count during monsoon than post and pre-monsoon [53]. At Nowshera, decrease in water availability and poor water quality had been reported [54]. A study from Afghanistan regarding impacts of wastewater use for irrigation reported high Zn, Pb and pathogens which are the major health risk for population of Kabul City [34,55]. Similarly, another study reported that 40% samples were found contaminated with *Vibrio cholerae* collected after monsoon flooding from district Peshawar [39,53]. A study reported the lack of access of clean water in Afghanistan due to increase in population and migration. The study reported the water, sanitation and management are the key issues in the country [56]. Temperature variation and increase nutrients along with low salinity and alkalinity supporting the growth of algae like Cyanobacteria. Water quality index was found medium (50–70) to poor (25–50) as per 100-point index range [55,57].

Due to warmer air temperatures, water temperature will increase by 2025, 2050 or 2080 with reduction in ice thickness as suggested by multiple studies. Due to warmer water temperatures, reduction in the concentrations of NH_4–N, NO_3–N, and PO_4–P was forecasted [58]. In rivers, the nutrient concentrations are reduced when the air temperature rises. Thus, the growth of phytoplankton also increases because more algae feed on the nutrients and reduce nutrients concentration in water bodies [23,59]. The concentration of dissolved oxygen in River Thames decreases slightly because of increased BOD and reduced saturation concentrations of DO recommend by Cox and Whitehead [4]. In context of climate change, it is observed that increased oxygen demand and higher water a temperature amplifies the release of nutrients from rocks and sediments, ensuing in nutrient rich water column [38,60,61]. Similarly, hydrometeorological modelling (SWAT) was used to test the concentration of *E. coli* in the KR which showed increased surface air temperature and precipitation in future (as expected due to climate change) may increase concentration of *E. coli*. The study indicated the highest concentration of *E. coli* in the monsoon which makes it unfit for use for different purposes [62].

According to report published by UNDP [63], missing research gap of impact of climate change on water quality issue in Pakistan. As change in climatic conditions like change in temperature and humidity, change in rainfall pattern, flood and droughts conditions affect the water quality of the water sources. Climatic conditions cause waterborne, and water related diseases like cholera, malaria, dengue fever, yellow fever etc. Increase in temperature and precipitation may increase the intensity of floods [64] which can ultimately affect water quality in the KR.

4.2. Impacts of pollutants in Kabul River on aquatic life and human health

Pollution level has been investigated and empirical studies have indicated the water quality deterioration of Kabul River. There have been great variations in ground water quality of Kabul River Basin (KRB) such as low concentrations of TDS considered to be excellent while on the contrary, high concentrations of pollutants estimated to be worst [64]. Both chemical and biological pollutants have influenced the surface water quality of Kabul River as most of the industries including textiles, cement, food processing, mining, petrochemical, fertilizers and others, generating and throwing their waste directly into the river, thereby increasing sulphides (680 times more than permitted), heavy metals, and dissolved oxygen [21]. Increased sulphides and organic pollution level is alarming as tanneries throwing their waste into the river directly [35]. Surface water quality has been deteriorated by anthropogenic and industrial activities; nature of pollutants depends on the type of contributing industry [21]. Another study reported the high nitrite levels and growth of bacteria in water. Water treatment plants must be installed especially at the paper industries before throwing waste into Kabul River [35]. Water usage for drinking and agricultural purposes has serious concerns, as polluted water has high risks both on crops and aquatic life. A study conducted on chemical pollution (sulphides and COD) impacts of Kabul River on fisheries especially in the industrial zones reported the high level of organic and inorganic pollutants adversely effected the fish population [35,64]. Similarly, research reported heavy metals effects on aquatic life. Native species like *Ompok bimaculatus*, *Aorichthys seenghala*, *Wallago attu*, *Labeo dyocheilus* and *Cyprinus carpio* were examined and it was revealed that the concentrations of nickel, chromium, zinc, copper and lead were higher than recommended dietary allowance of USA in liver and muscles of the studied species [3,65]. They suggested that regular eating of fish contaminated by heavy metals may cause serious health issues. Health issues have not been identified as fish is not a staple food and consumed regularly. Other studies demonstrated the bioaccumulation of heavy metals like higher concentrations of zinc and lowest concentrations of mercury. The concentrations of Cr, Ni, Pb, and Cd also crossed permissible limits and caused serious health risks to consumers of fish [66,67]. Presence of persistent organic pollutants (POPs) in fish population is cancer causing to consumers of contaminated fish [68]. Limited studies have been published on indirect effects of contaminated Kabul River water on human health. But direct impact on aquatic life has been observed through literature survey. No data has been found showing direct impacts of contaminated water on human health. More studies are suggested on this aspect to clear the picture and raise awareness among public consuming fish as food. Water virtually impacts health, food, energy, and economic output.

Natural disasters like the 2005 earthquake in Pakistan have shown the fragility of water supplies by municipal authorities. The availability of clean water in Pakistan is a complex issue that requires targeted solutions through the implementation of integrated technology base. One of the studies revealed 101 deaths per 1000 children in Pakistan due to water-borne diseases. It was reported that almost 60% child mortalities in Pakistan are caused by sanitation diseases while diarrheal diseases kill more than 200,000 children of under-five. Poor hygiene and unhealthy water

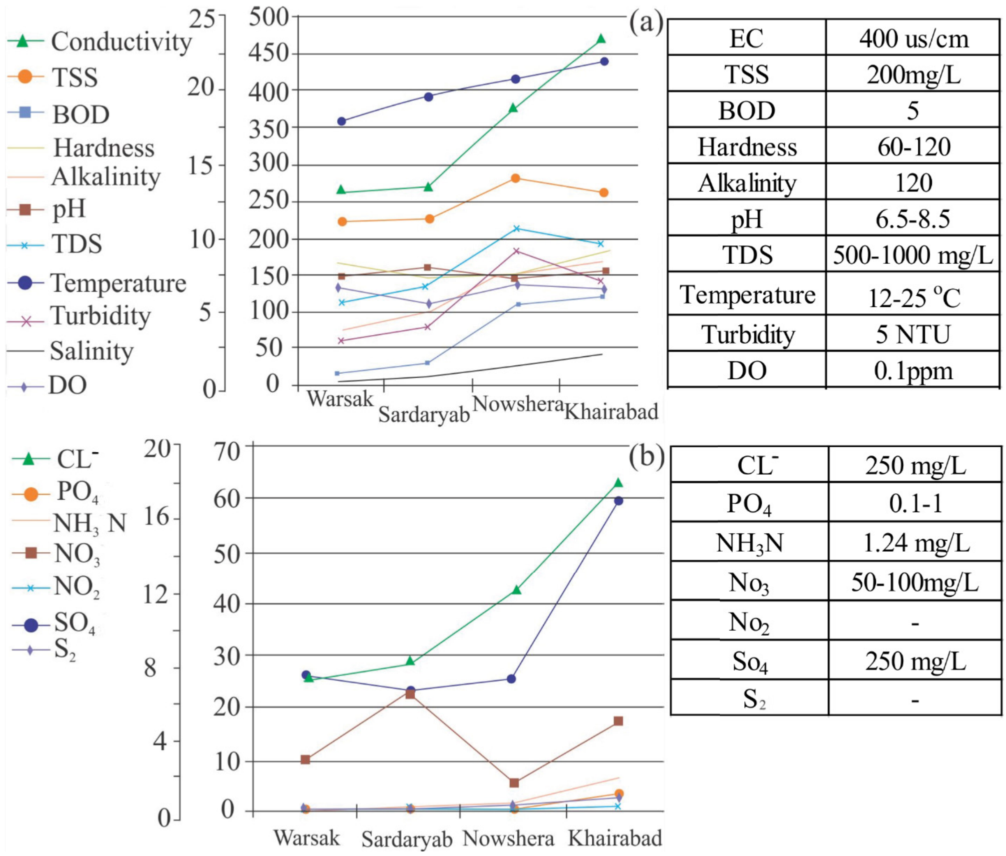

Fig. 2. (a and b) Chemical quality of different variables of KR at sampling sites along with WHO guidelines [36].

consumption may result in much costly treatments for water borne illnesses, reduced work capacities and school performance of children. Disinfecting water from pathogens is perhaps the single most important aspect of providing safe water for the people of the world. However, traditional disinfection technologies like potent oxidants and chlorine are not suitable for most of the developing world. Moreover, disinfection using traditional oxidizers can create potent disinfection by-products (DBPs), which can harm people in both the developing and developed countries. Natural materials derived from clays, kimberlites, zeolites, and medicinal plants have properties that can have great efficacy as absorbents, ion-exchangers, catalysts, and photocatalysts for water purification. For remediation of ground, surface and drinking water, carbon nanotubes, zeolites, single enzyme nanoparticles, and nanoscale semiconductor photocatalysts are used. Zeolites comprise about 40 naturally occurring and over 180 synthetics nonporous alumino silicates. The substitution of Al^{3+} for Si^{4+} within their framework structure results in a negatively charged surface. Zeolites have high thermal stability, high surface area, large ion exchange capacity, and tunable selectivity, making them attractive candidates for adsorption of environmental pollutants like cations like Pb^{2+}, Cd^{2+}, Cu^{2+}, Cr^{3+}, As^{3+}, Hg^{2+}, anions, for example, CrO_4^{2-}, AsO_4^{3-}, F^- and organics like benzene, toluene, ethyl benzene, and xylenes (BTEX), chlorinated organic, pesticides, and polynuclear aromatic hydrocarbons (PAHs) [11,22,62,69–71]. The yearly social rate of return can reach $160 billion if 1% of 1.7 million mortalities from diarrheal diseases are prevented by water disinfection through Mills–Reincke multiplier [49,71]. The discharge of effluents and heavy metals comes from sewage, industrial waste, and agricultural run-off. On the other hand, natural processes such as earthquake, landslides, tornadoes, cyclones, erosion, and weathering of rocks lead to the production of heavy metals. It has been studied that zinc, cadmium, lead, chromium, copper and nickel have deposited in fish and contributed to toxicity in food chain [43].

In arid regions, the hydrological regime is affected by climate change and global warming [72], 209 species of algae and Cyanobacteria in Kabul River were examined by [73]. The species abundance and richness increase at downstream catchment area of river, mostly represented by charophytes. The nature and extent of water pollution is examined through accumulation of heavy metals in living organisms. Kabul River is highly unclean because of the presence of heavy metals from variety of sources. To preserve fish habitat and reduce health risks, the water quality needs to be checked on monthly basis. The pollution load of heavy metals in common fish population was addressed by Hazara University, Pakistan. Fish species like *Wallago attu*, *Aorichthys seenghala*, *Cyprinus carpio*, *Labeo dyocheilus* and *Ompok bimaculatus* were monitored for pollution from Peshawar Valley of Kabul River. The concentrations of zinc and chromium were very high in fish population than cadmium and lead. Zinc, nickel, cadmium, chromium, and

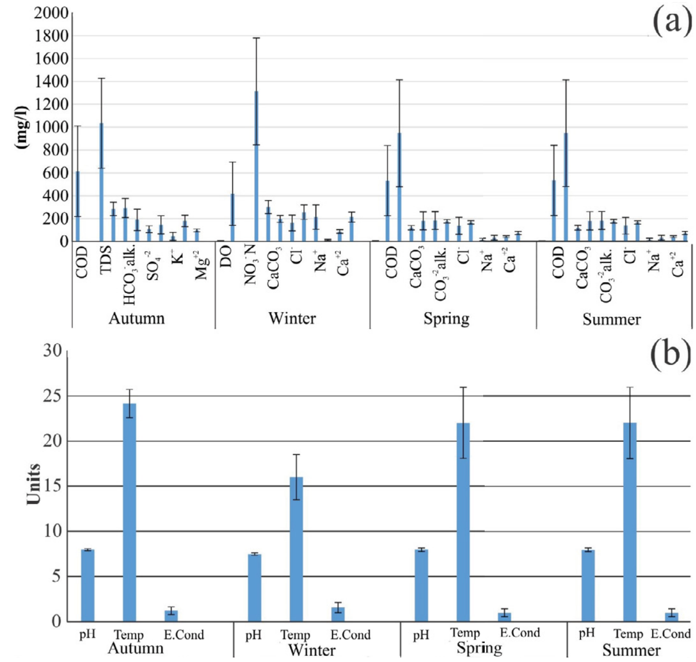

Fig. 3. (a) Analysis of different parameters effluents and receiving water during different seasons and (b) analysis of pH, temp., EC during different seasons (Adapted from Bhatti and Latif [43]).

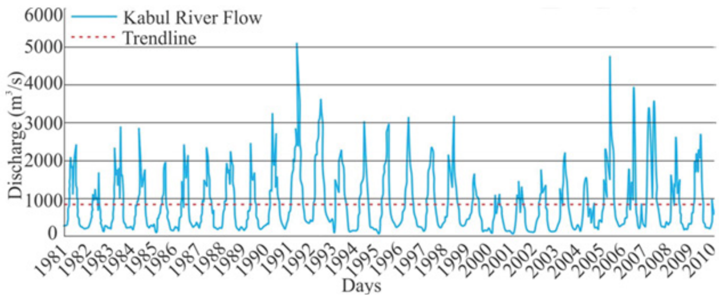

Fig. 4. Kabul River discharge and availability for agriculture [76].

lead concentrations in fish samples also exceeded RDA limits. Multiple health problems may arise on larger scale due to contaminated fish species, needs proper attention on local and national level [33]. Multiple sites were selected such as Shah Alam, Naguman Branch and lower Main River for monitoring organic pollution and sulphide concentrations respectively while chromium concentrations in the three branches and the Bara River were also studied through literature survey. Near Shah Alam, dissolved oxygen concentrations decrease in downstream area while the levels of ammonia are also extremely stressful. During low flow conditions, the situation becomes worst because of low dilution in river. In another study, 3.5 mg/L organic matter below Nowshera DDT Factory and Sarhad Colony Textile Mill were reported [35]. In water bodies, Cr(III) is said to be less toxic to the aquatic life while Cr(VI) is toxic and carcinogenic to aquatic life and human beings. Metals move onto different layers in water bodies as the aquatic ecosystems lack natural removal processes of metals. These metals produce detrimental effects in every compartment of aquatic ecosystem [52]. Modelling approach (SWAT) was used for the transport and fate of *E. coli* and reported that livestock manure and human faeces coming from big cities contribute 44% of *E. coli* concentration [74,75]. Similar kind of studies for other parameters are lacking and recommended in future.

4.3. Suitability of Kabul River water for agriculture

Water is the basic requirement for agriculture several crops including maize, *Brassica*, tobacco, vegetables, and fruits are grown in the vicinity of the Kabul River in Pakistan. These crops require suitable quantity of water. Discharge variations up to year 2010 in the graph (Fig. 4) displays more or less constant discharge from 2000 onward attributed to rising temperature triggering the glacier melting as a result the river discharge increases. Another important parameter in assessing the suitability of water

Table 1
Hydrochemical analysis parameters of surface waters of the Kabul Basin 2005 [44]

S#	Samples location	pH	EC	K	Na	Cl	Mg	Ca	NH_4	TIC	NPOC	SAR
	Units		μS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
1	Kabul River (KR-Camp Warehouse – Artang	9	2,200	9.6	248	263	137	39.7	0.02	114	4.3	4.19
2	Bridge-Paghman River	7.7	919	7.1	62.7	69.5	48.6	66.9	–0.01	84.1	86.7	1.42
3	Darulaman	8.2	3,000	55.3	344	248	53.3	101	114	228	48.4	6.89
4	Paghman River-Spring	6.7	173	1	6.7	5	565	20.7	–0.01	19.9	0.8	0.34
5	Logar River-Bagrame 1	8.6	1,500	6.7	114	114	116	41.2	0.02	116	3	2.06
6	Logar River-Bagrame 2	8.6	1,470	6.8	117	119	119	39.6	0.09	114	2.6	2.1
7	Kharga Lake	7.1	162	1.4	5	3.2	4.38	22.5	0.01	17.8	1.9	0.25
8	Karez Amin	8	327	3.2	9.7	4.8	8.68	47.1	–0.01	34.6	1	0.34

TIC = Total Inorganic Carbon; NPOC = Non-Purgeable Organic Carbon; NA = Not Analyzed; NN = Not Known;
Negative values = Values below detection limits.

for irrigation is the "sodium adsorption ratio" (SAR), is an index of the potential of a given irrigation water to induce sodic soil conditions. (Soil sodicity is usually measured by the percentage of a soil's cation exchange capacity that is occupied by sodium ions) [74]. The risk is that high sodium concentrations can cause negative changes to the soil structure because of the shrinkage this causes to swelling clay minerals [10,44] and, is calculated from the sodium, calcium and magnesium concentrations in the water:

$$\text{SAR} = \frac{\text{Na}^{+}}{\sqrt{\frac{1}{2}\left(\text{Ca}^{2+} + \text{Mg}^{2+}\right)}} \quad (1)$$

Where sodium, calcium, and magnesium concentrations are expressed in milli-equivalents/liter.

By irrigation with sodium-rich water, soil sodicity is induced.

The negative effects associated with sodium affected soils, include; reduced crop yield and quality because of sodium uptake through the roots of sodium sensitive plants; impaired soil physical conditions, as manifested by reduced soil permeability infiltration rate and hydraulic conductivity and an increased tendency for hard setting; and reduced crop yield and quality [77]. Kabul River Basin is also polluted by organic nutrients coming from Swat River (one of the tributries of KR) which indicates the agriculture activities in the surroundings [55].

4.4. Impacts of climate change on Kabul River and its tributaries

Impact of climate change is more vital in Pakistan because in Pakistan has different weather conditions. Climate change can have a solid influence on river flows in Pakistan. Glaciers cover around 13,680 km^2 which is 13% of the mountainous regions of the Upper Indus Basin (UIB) [35,78,79]. Snowmelt and glaciers melt, water from these glaciers contribute significantly to the river flows in Pakistan. Changing in temperature and precipitation pattern could have impact on river flows of arid and semi-arid regions [78]. Variations in magnitude flow are expected to increase rigidities among the provinces, specific in the downstream areas, regarding reduced water flows in the dry season and high flow of water and resulting flood problems during the wet season [80]. Climate variability and especially change in rainfall patterns have significant impacts on water quality. Flash flood may spread agricultural and other wastes into subsurface waterbodies. A study conducted on projection of climate change scenario (temperature and precipitation) in the KR basin in Afghanistan on the data between 1960–1980 and reported projected increase in temperature by 1.8°C in 2020, 3.5°C in 2050 and 4.8°C by the 2080. However, the precipitation projected to increase or decrease according to the monthly river basin precipitation, but annual precipitation will increase by 2100 [81]. KR is included in one of the intermittent rivers because of high seasonal variation in the suspended sediments transport, flow and habitat [78].

In terms of discharge the climate projections suggest a decrease in discharge as compared to the baseline. This decrease is projected in the months from April to September (Fig. 5). The projected decrease is attributed to the fluctuations in temperature and precipitation patterns [82].

The investigation of Chitral River as one of the main tributaries of Kabul River and the second largest river in Pakistan are exposed that variation in temperature has a deep effect on the snow/glacial melt in comparison to the mean monthly rainfall. Chitral River is feed by the snow and glaciers melting and in winter season receives a lot of snowfall. While in monsoon period 30% discharge rate of river remains above from the mean value, while 60% discharge rate is less than the mean value in pre-monsoon period as shown in Fig. 6 [58].

Annually average precipitation during (1957–77 and 2003–06) in the Kabul Basin is about 330 mm/y but now it has varied considerably in the past few periods [44,45]. Past observations of temperature from (1961–91) and recent (2003–07) mean monthly temperatures in the basin indicate apparent warming drift about 2°C temperature increase per decade since the early 1960s [45]. According to 4th assessment report of the IPCC, [72] recognized climate patterns is in Southwestern Asia contain warming trends. The next 50 y,

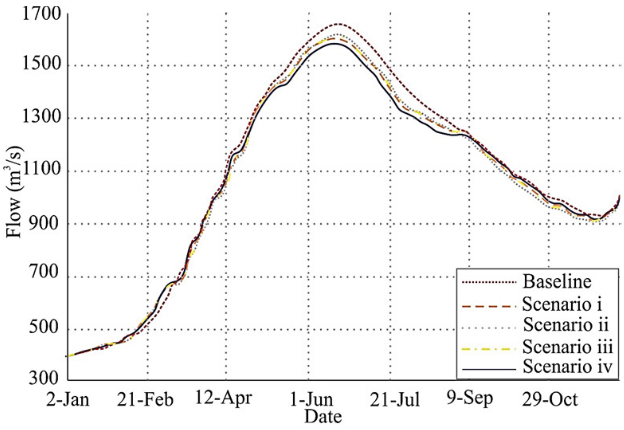

Fig. 5. Climate change scenarios of future discharge in KRB, Baseline year (2002), Scenario 1 (2025), Scenario 2 (2050), Scenario 3 (2075), Scenario 4 (2100) [82].

a 10% reduction in total annual precipitation is anticipated in Afghanistan. Increasing surface temperatures in mountainous regions would be reduced snowpack's and cause snowmelts to arise earlier from the season.

In the Kabul Basin 10% decrease in recharge was simulated to evaluate the hydrologic effect of potential climate change on groundwater resources. The annual mean of the Kabul River flow during (1977–2015) was 26.32 billion (10^9) m^3 (BCM) with a range of 13.77 to 42.2 BCM and standard deviation of 6.026 BCM revealed no significant trend in annual inflow data [58,80].

5. Conclusions

Water quality of Kabul River Basin is severely affecting the health, agriculture, and aquatic life in surrounding areas of river. The effect of climate change is obvious and future projections show that situation will get worse with passing time. The main sources of water contamination in Kabul River Basin are the presence of increased fecal coliform and high concentrations level of nitrate, which indicate that Kabul River Basin water systems are contaminated by microbial pathogens and anthropogenic contamination; thus, pose a threat to the health of inhabitants living around the vicinity of Kabul River. The river is polluted by organic nutrients coming from Swat River (one of the tributaries of KR) which indicates the agriculture activities in the surroundings. The discharge graphs of Kabul River depict good results and climate projection in terms of water availability indicate a gradual decrease in river discharge with time.

The aquatic life is under serious threat as presence of several heavy metals were indicated in native species like *Ompok bimaculatus*, *Aorichthys seenghala*, *Wallago attu*, *Labeo dyocheilus* and *Cyprinus carpio*, in addition to that the number of other native species are also decreasing. Health experts fear that the long-term utilization of these species may cause serious health hazards for human population.

During the study, it was observed that limited studies has been conducted on water quality of Kabul River with reference to climate change and it has been suggested to conduct more work on the missing research gaps. Pakistan and Afghanistan should work on cooperation between the countries regarding knowledge sharing, future water planning, and management and on technical information related to Kabul River. Lack of dialogue between countries may create tension and dispute on the use of water. Water pollution in the river may affect health, agriculture, and economy of both countries. There is need to work on reduction of pollution level especially owners of the industries should treat water before throwing it into the Kabul River. Local government may intervene on this aspect to implement the environmental laws regarding pollution in the rivers. Institutional cooperation is important under changing climatic conditions to resolve the conflict on Kabul River between two countries as both the countries, are at the same time, upper riparian as well as lower riparian.

6. Recommendations for action

The following are the important recommendations to improve the water quality of Kabul River:

- A detail work regarding hydrogeology of Kabul River within the Afghanistan region is required. The available data sets are very old, they should be replaced with new research. Detail regarding the water quality is not available for Kabul River within Afghanistan, a detailed study of water quality parameters is desired for Afghanistan part of Kabul River.
- Recycling of industrial and domestic waste products and its conversion into by-products before spreading it into rivers. Integrated solid waste management

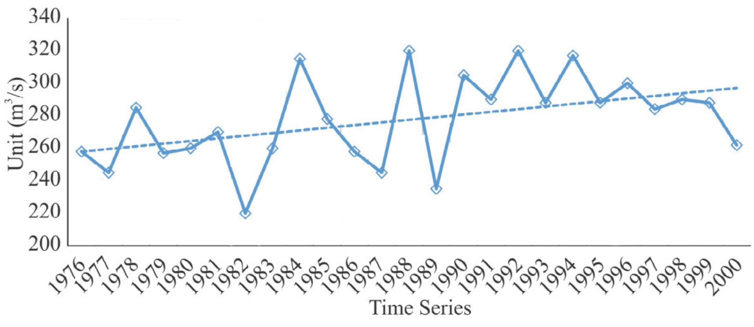

Fig. 6. Hydrograph of mean annual discharge of Chitral River. *Source*: Khalid et al. [58].

strategies should be adopted along with installation of waste treatment plants at the source may help in decreasing pollution in the Kabul River.

- Educating people and raising awareness among the residents of Kabul River Basin about the negative consequences of ground and surface water contamination and impacts on their health through media, universities, colleges, schools, mosques etc. may help in decreasing both pollution level and impacts on human and aquatic life.
- Regulatory authorities at city level in both the countries (Pakistan and Afghanistan) and strengthening institutions for formulation and application of water resources related policies along with implementation of regulations may help in reducing the pollution levels and water quality monitoring must be ensured in pre-and post-monsoon period in both the countries.
- The water experts of both the countries suffer due to lack of availability of clear data sharing policy. Therefore, it is highly recommended to develop a comprehensive data sharing policy both at individual and governments level.
- Strong cooperation and coordination among water experts of both countries for sharing experience and knowledge is important and can help in improving the existing scenario.

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Author contributions

Toqeer Ahmed and Umair Bin Nisar mainly led this paper; other all authors made useful contributions in different sections of the paper and supported in completion of this work.

Conflicts of interests

The authors declare no conflict of interest.

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